RESEARCH HIGHLIGHT
Office of Basic Energy Sciences
Geosciences Program

Project: Cation Diffusion Rates in Selected Minerals

Who and Where: Randall T. Cygan and Diana K. Fisler; Geochemistry Department, Sandia National Laboratories, Albuquerque, NM 87185-0750

Objective: Determine experimental cation diffusion coefficients for carbonate minerals at temperatures less than 1000°C for evaluating disequilibrium behavior in geological, nuclear waste, energy, and materials concerns.

Results: The presence of zoned iron, magnesium, calcium, and manganese in the carbonate phases associated with the cracks and inclusions of the ALH84001 meteorite provides evidence for constraining the thermal history of the meteorite. Using self- and tracer diffusion coefficients obtained from laboratory experiments on natural calcite, cooling rates are calculated for various temperatures and diffusion distances to assist in the evaluation of the compositional zoning associated with the carbonate phases in ALH84001. The closure temperature model provides the average temperature below which compositional zoning will be preserved for a given cooling rate, that is, the temperature at which diffusion will be ineffective in homogenizing the phase. The validity of various theories for the formation of the carbonate globules may therefore be examined in view of the diffusion-limited kinetic constraints. Experiments using a thin film-mineral diffusion couple and ion microprobe for depth profiling analysis were performed for the temperature range of 550-800°C to determine self- and tracer diffusion coefficients for calcium and magnesium and in calcite. The resulting activation energies for calcium (E_a(Ca) = 271 $\pm$ 80 kJ/mol) and for magnesium (E_a(Mg) = 284 $\pm$ 74 kJ/mol) were then used to calculate a series of cooling rate, grain size, and closure temperature curves. The data indicate, for example, that by the diffusion of magnesium in calcite, a 10 µm compositional zone would be completely homogenized at a temperature of 300°C for cooling rates less than 100 K/ma. These data provide no constraint on formation models that propose a low temperature fluid precipitation mechanism, however, they indicate that the carbonate globules were not exposed to a high temperature environment for long time scales following formation.

Significance: This research presents the application of our experimental cation diffusion results to the understanding of zoning patterns observed in the carbonate globules of the Martian Allan Hills 84001 meteorite. The thermal history model helps to identify the temperatures and times that would have led to the preservation of the quenched zoning profiles for Fe, Mg, Ca, and Mn. The diffusion data and model strongly indicate that any high-temperature environment was probably short lived.

Publication: Fisler, D. K. and Cygan, R. T. (1999) Cation Diffusion in Calcite: Determining Closure Temperatures and the Thermal History for the Allan Hills 84001 Meteorite. **Meteoritics and Planetary Science**, 33, 785-789.